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Stafford et al.

[11] **3,824,942**

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[54] **OFFSHORE UNDERWATER STORAGE TANK**

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[52] **U.S. Cl.** ..... **114/0.5 T,** 61/46

[51] **Int. Cl.** **B63b 35/44**

[58] **Field of Search** ..... 114/0.5 R, 0.5 T, 16 E, 114/65 A; 61/46, 46.5

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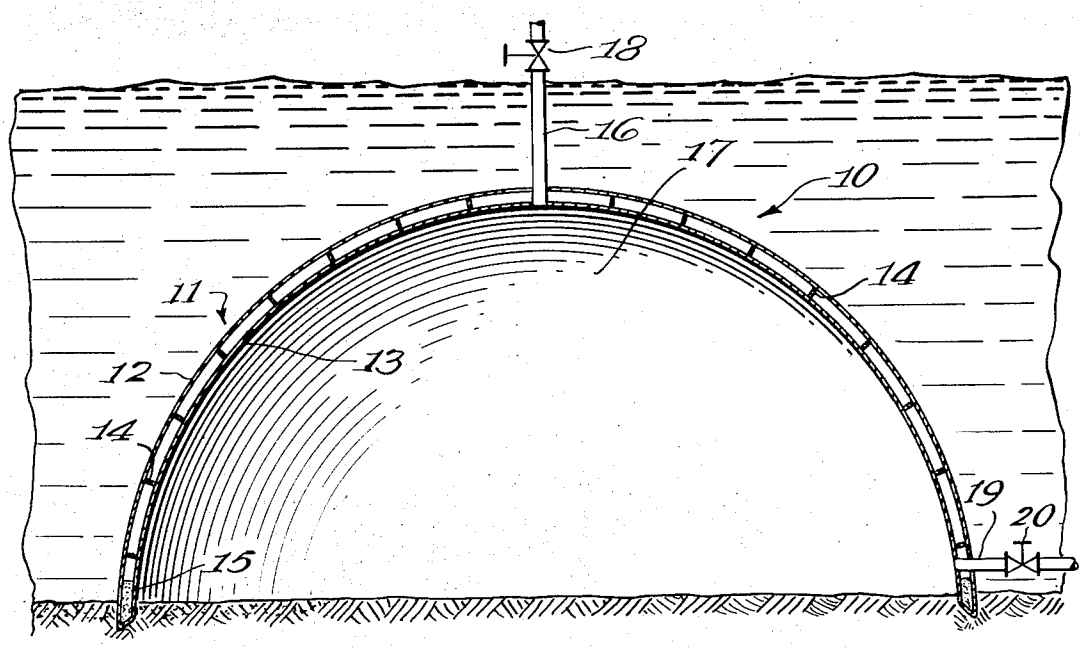
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[57] **ABSTRACT**

An offshore storage tank, to be placed on a sea floor, having a dome-shaped rigid continuous enclosure, open at the bottom, a buoyant chamber in the enclosure extending over a large part of the area of the enclosure and positioned and sized to provide buoyancy balance or equilibrium to the tank when the tank is floating on water with or without any amount of air in the large volume defined by the enclosure, a conduit to remove air from beneath the enclosure to lower it in water.

The enclosure can constitute two spaced apart rigid domed shells with rigid connecting members joined to each shell to hold them in fixed position relative to each other, with a concrete ring closing the bottom of the enclosure between the shell ends thus defining a hollow enclosed space between the shells.

1 Claim, 9 Drawing Figures



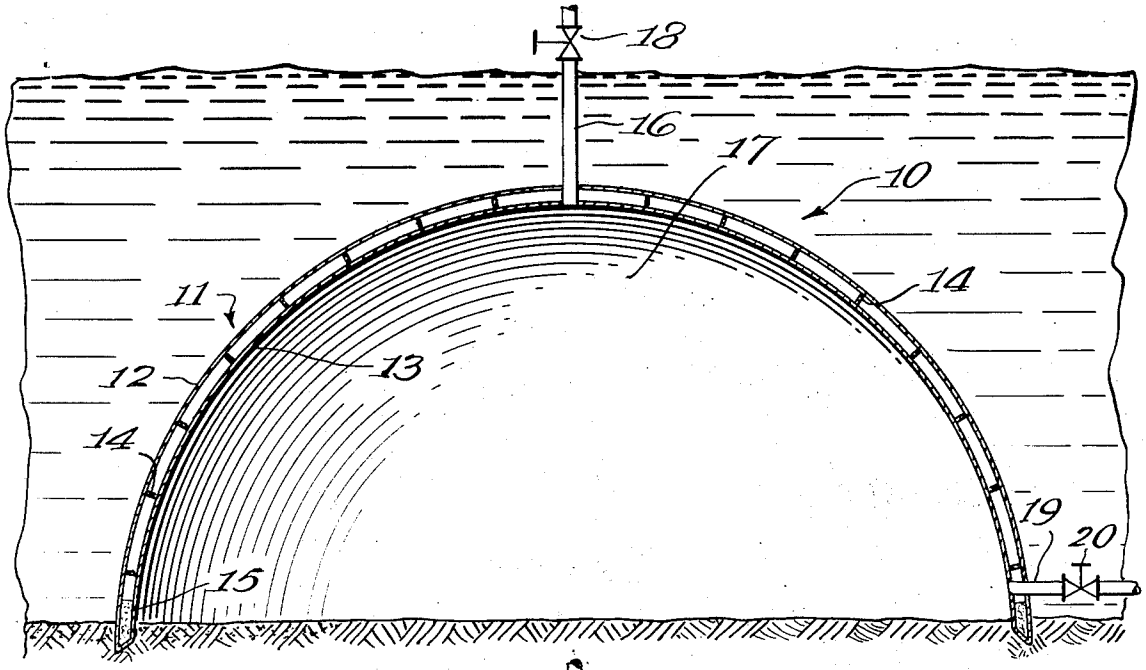


Fig. 1

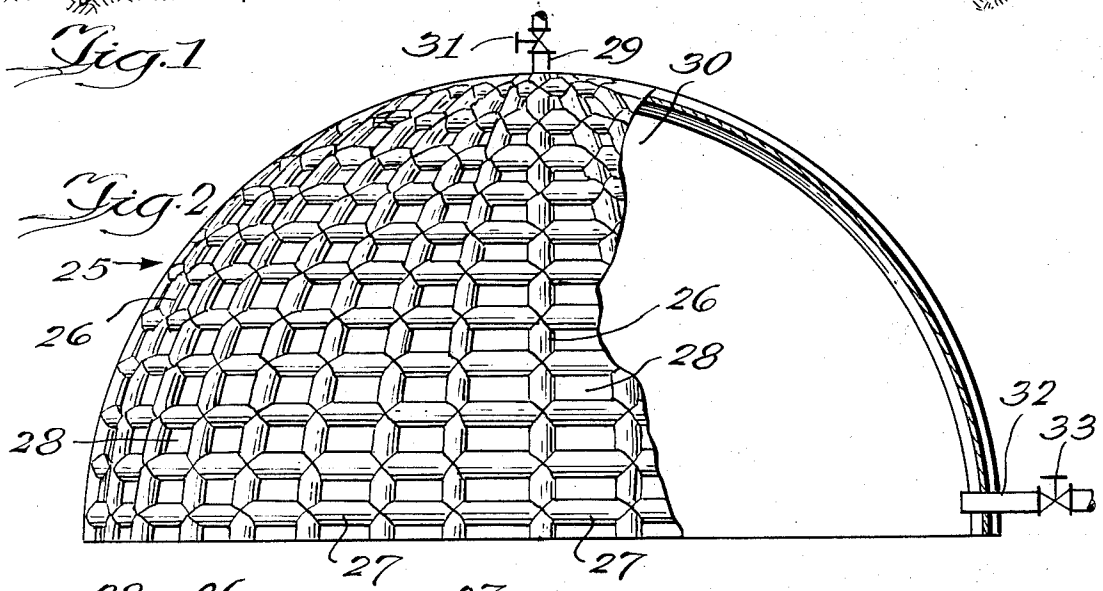


Fig. 2

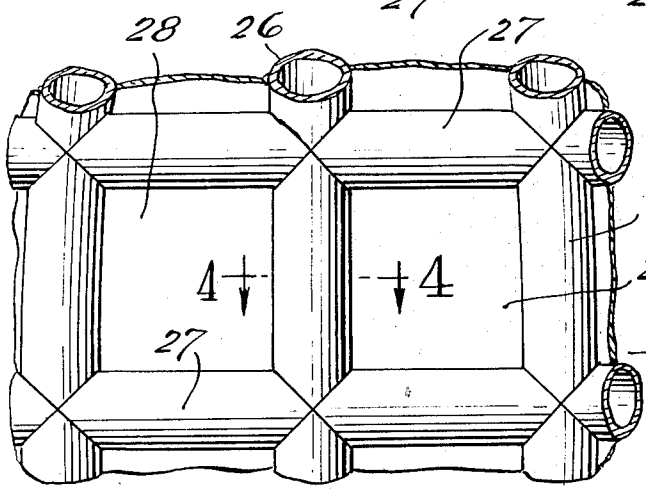


Fig. 3

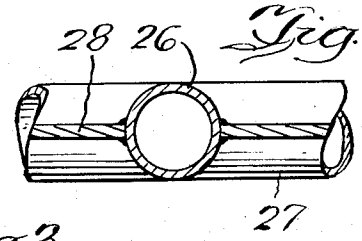


Fig. 4

Fig. 5

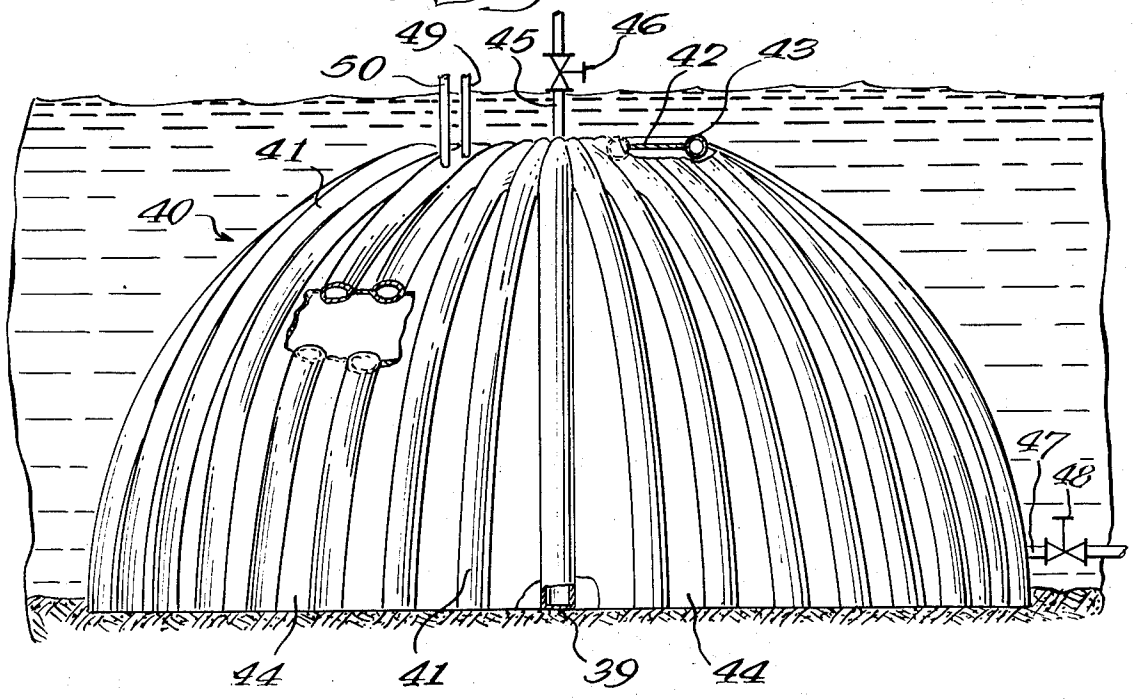
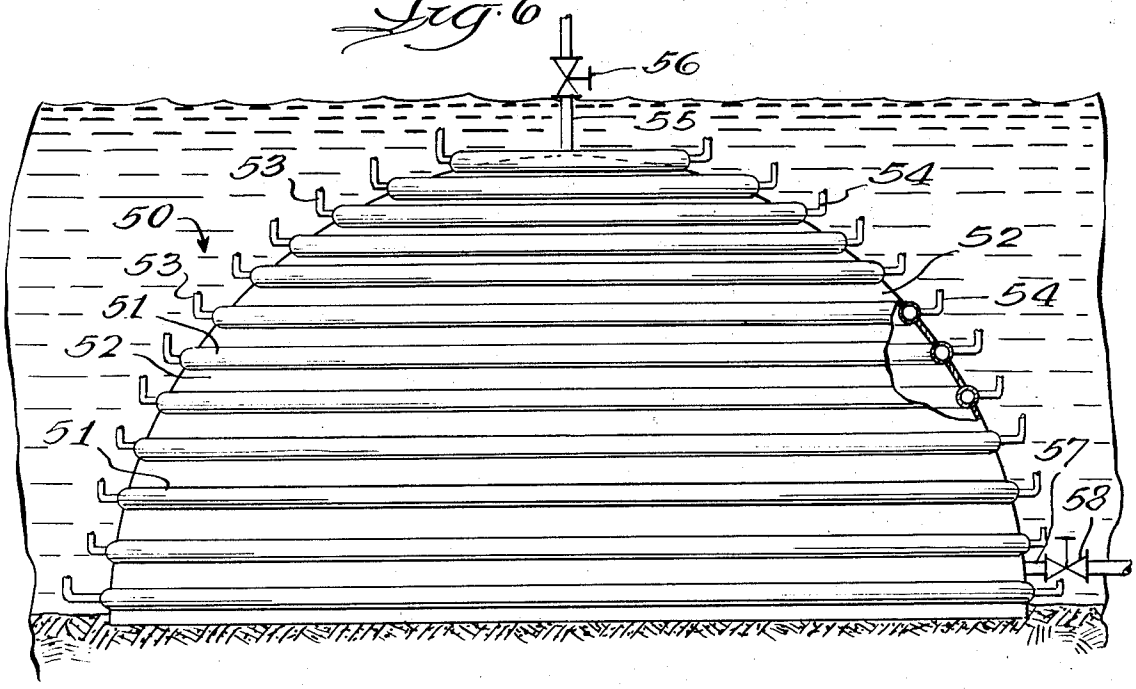

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Fig. 6


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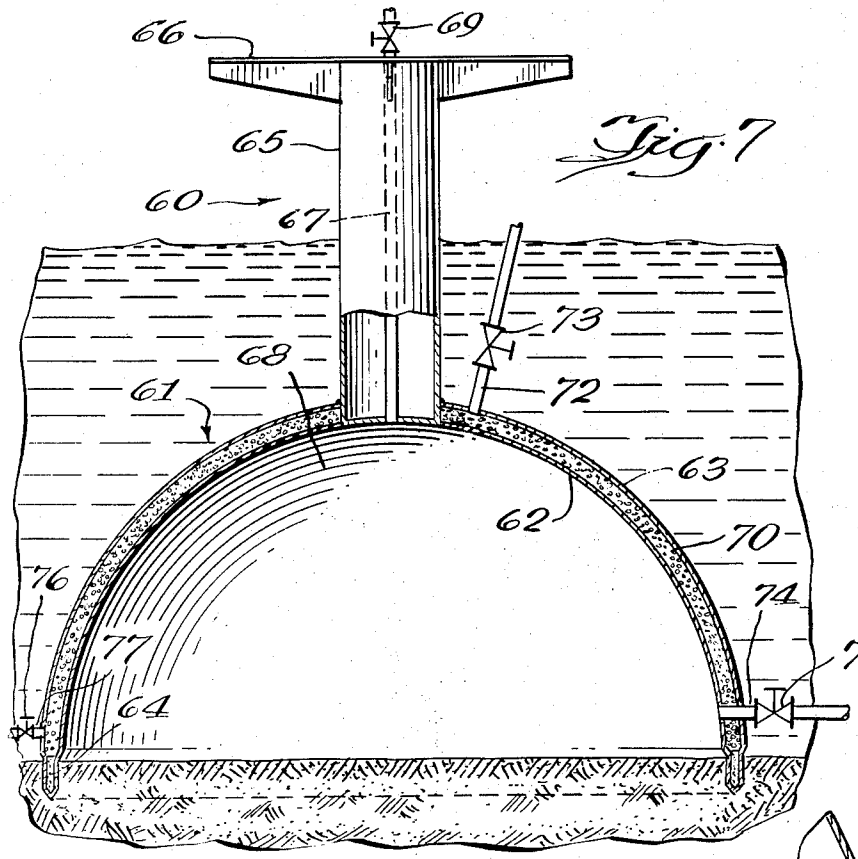


Fig. 7

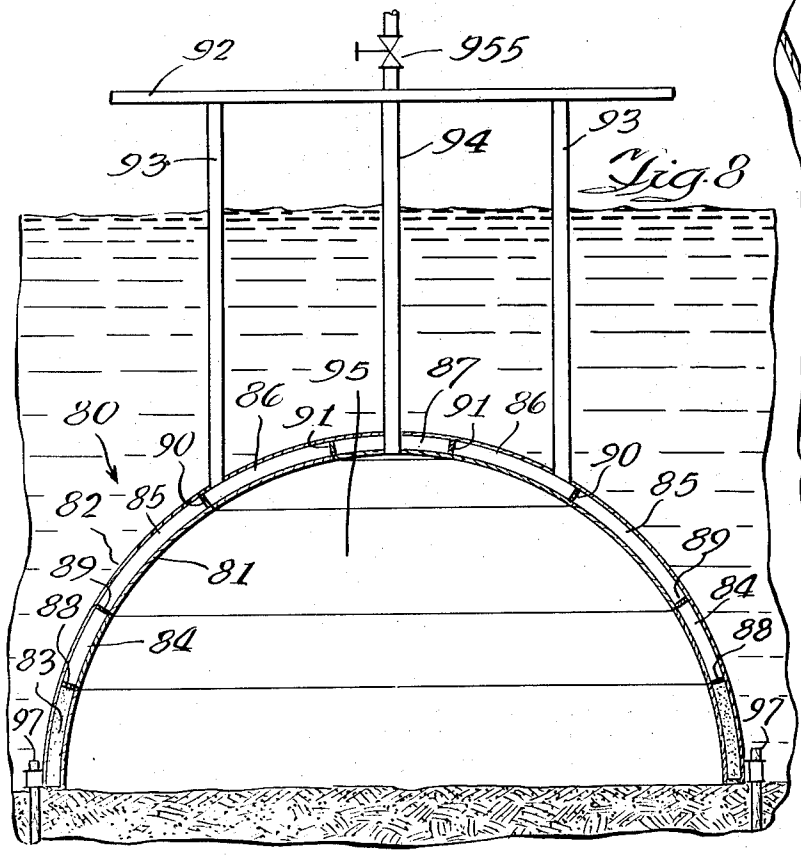


Fig. 8

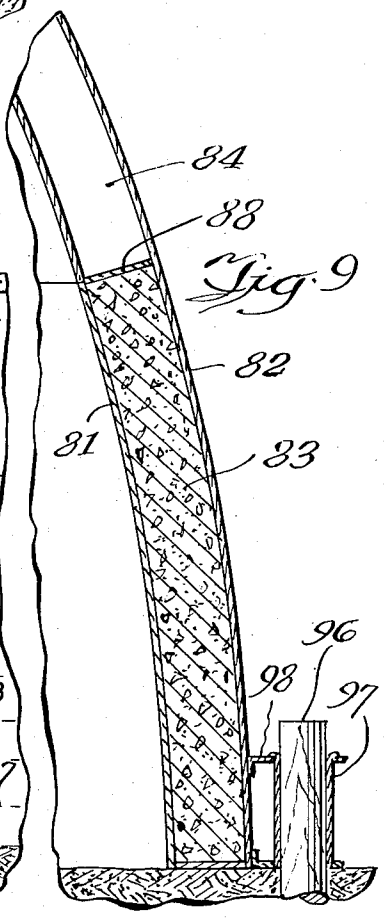


Fig. 9

OFFSHORE UNDERWATER STORAGE TANK

This invention relates to tanks for storing liquids. More particularly, this invention is concerned with an offshore liquid storage tank which can be floated to a site and submerged. Although other liquids may be stored which have specific gravities less than the specific gravity of water, the tank is particularly useful for storing oil and liquid hydrocarbon products derived therefrom.

Large amounts of oil are obtained from offshore wells many miles from the nearest shoreline. Because of the water depths encountered in offshore oil production, as well as surface and underwater currents and storm potentials, the provision of storage tanks at the site has presented many engineering problems. The large size of the tanks, and the problems involved in building them offshore, has so far made it essential that they be built completely, or in major components, on land and transported to the offshore site for positioning or erection.

Transporting tanks to an offshore site has usually required floating them, with all the problems of buoyancy and stability, plus structural integrity, that this involves. Upon arriving at the site, the tanks must be lowered until they are supported by, or rest upon, the floor or bed of the body of water. As tank buoyancy is decreased, floating stability varies, with capsizing a constant threat. Thus, experience has shown a definite need for offshore oil storage tanks which can be floated to a site with stable buoyancy and then submerged to be supported by the floor of the body of water while maintaining control of the tank against unstable dangerous listing or tilting and with full control of the descent.

There is accordingly provided by this invention an offshore liquid storage tank, floatable to a site for positioning on the floor of a body of water, of such design and shape as to possess unusually stable buoyancy while floating and when submerged. The tank can be built of a size and capacity considered most suitable for a particular offshore location. Strength against underwater turbulence and pressure is also a feature of the tank provided by this invention.

The offshore storage tank of this invention has a generally dome-shaped rigid continuous enclosure, open at the bottom, surrounding or defining a large volume. The dome-shaped enclosure can be of any suitable shape which will define a volume therebelow. In horizontal section, it can be circular or polygonal or a combination of straight and arced segments. In vertical section through its axis, the dome-shaped enclosure can be conical, a circular or elliptical segment or a combination thereof. However, the peripheral edge of the dome-shaped enclosure advisably lies in a horizontal plane and is adapted to rest on a sea floor.

The dome-shaped enclosure has integral buoyancy means extending over a large part of the area of the enclosure. The buoyancy means is positioned and sized to provide buoyancy balance or equilibrium to the tank when the tank is floating on water, with or without any amount of trapped air beneath the enclosure. Means is also included to remove air from beneath the enclosure to lower the tank into the water. In addition, means is provided to add ballast to, and remove air from, the buoyancy means to submerge the tank for lowering it to the floor of a body of water.

The invention will be described further in conjunction with the attached drawings in which:

FIG. **1** is a vertical sectional view of an offshore tank having an enclosure comprised of two concentrically arranged semispherical shells;

FIG. **2** is an offshore storage tank having an enclosure which is semispherical and in which the buoyancy means comprises spaced apart horizontally positioned hollow tubular ribs, and vertically positioned hollow tubular ribs which radiate outwardly and downwardly from the top of the enclosure;

FIG. **3** is an enlarged view, partially in section and partially broken away, illustrating in greater detail the enclosure structure of FIG. **2**;

FIG. **4** is a sectional view taken along the line **4—4** of FIG. **3**;

FIG. **5** is an elevational view, partially broken away, of an offshore storage tank in which the enclosure has tubular buoyancy ribs which radiate outwardly and downwardly from the top central portion of the enclosure;

FIG. **6** is an offshore storage tank in which the enclosure is a dome-like shape having a plurality of spaced apart hollow tubular ribs or toroidal elements for buoyancy;

FIG. **7** is an elevational view, partially in section, of an offshore storage tank in which the enclosure comprises two spaced apart semispherical shells with a tubular column mounted thereon and projecting to above sea level;

FIG. **8** is an elevational view, partially in section, of an offshore storage tank in which the enclosure comprises two spaced apart concentric semispherical shells having bulkheads between the shells to divide the space therein into separate horizontally positioned airtight circular compartments; and

FIG. **9** is an enlarged vertical sectional view showing the bottom portion of the closure of FIG. **8.**

Each of the enclosures shown in the drawings is essentially circular in horizontal section and is open at the bottom. The enclosures are rigid and made of metal unless otherwise stated.

With reference to FIG. **1,** the offshore storage tank **10** has an enclosure **11** which has an outer semispherical metal shell **12** and an inner semispherical metal shell **13** concentrically positioned with respect to outer shell **12.** A plurality of internal braces **14** maintain the outer and inner shells **12** and **13** in fixed position relative to one another. The shells **12** and **13,** as well as the internal braces **14,** are made sufficiently strong to withstand the pressure exerted thereon when the tank is positioned on the sea floor at a locality for which the tank is designed. Enclosure **11** can be pressurized with air to aid shells **12** and **13,** as well as internal bracing **14,** in withstanding loads. Although it is not essential, it is highly advisable to provide a substantial ballast at the lower bottom edge of enclosure **11.** Thus, as shown in FIG. **1,** concrete **15** is placed between outer shell **12** and inner shell **13** in the lower bottom portion between such shells. The result is a ballast ring which extends completely around the circular bottom edge of enclosure **11.** Furthermore, the lower edge is advisably pointed or made wedge-shaped to facilitate penetration into the sea floor.

Conduit **16** is provided in the top portion of enclosure **11** and communicates with space **17** which is enveloped by the enclosure. Valve **18** is provided in con-

duit **16** to control flow through the conduit. Conduit **19** communicates with the bottom portion of the space or volume **17** defined by enclosure **11** and valve **20** controls flow through conduit **19.**

A tank such as described with respect to FIG. **1** can be built onshore next to the edge of a sea in a suitable graving dock. After the tank has been built, the graving dock can be flooded and the tank floated to sea. The tank will not have a substantial draft because it will float primarily on the air bubble which occupies the space or volume **17** enveloped by enclosure **11.** Furthermore, the tank will have excellent stability, even when it is constructed with the center of gravity above the center of buoyancy because of the wide cut-water plane of enclosure **11.** Because of the width of the enclosure wall, whether at the location of the concrete ballast **15** ring at the bottom edge, or the thickness of the wall at the spaced apart shells **12** and **13,** an effective righting moment is provided when the tank floats on the air bubble enveloped beneath the enclosure. If the enclosure was a single shell of small thickness, the cut-water plane would be so small as to provide very little righting moment and the tank would go into a state of instability and tilt out of control and capsize.

To submerge the tank shown in FIG. **1,** air is removed from the space **17** beneath enclosure **11** by means of conduit **16** with valve **18** open. Valve **20** can be kept closed because water flows into the lower part of space **17** from the surrounding sea when air is vented through conduit **16.** The continued removal of air through conduit **16** results in a progressive lowering or submerging of the tank into the sea. Such lowering however is achieved with total stability of the tank. When all of the air in space **17** is removed, valve **18** can be closed although if left open submerging of the tank is not adversely affected.

A tank of the general shape and construction as shown in FIG. **1** will usually have the center of buoyancy above the center of gravity when the tank floats with minimum draft on the sea surface. As air is removed from space **17,** the center of buoyancy moves with respect to the center of gravity until the center of gravity is below the center of buoyancy. As submergence of the tank continues with removal of air from space **17,** the center of buoyancy continues to migrate higher above the center of gravity with the result that the tank remains stable at all times during removal of air from space **17.**

Enclosure **11** is constructed so that when all air is removed from space **17,** the enclosure will be near neutral buoyancy but will still possess a small residual buoyancy. Such residual buoyancy is provided by the hard volume space between outer shell **12** and inner shell **13.** Such hard volume must be sufficiently large to provide the residual buoyancy required to overcome the effective weight of the tank components when the tank is essentially all below the surface of the sea. At such point the tank can be likened to an iceberg in that only a small part of the tank remains above the level of the sea. To complete submergence of the tank from such position, cables can be used to pull it to the bottom. Thus, cables can be run from the tank to anchored pulleys on the sea floor and from there to a winch on a barge on the sea surface or onto a tower placed on the tank itself. Once the tank has been cranked down onto the sea floor, it can be secured in position by means of piles or simply by filling the space between the outer shell **12** and inner shell **13** with a suitable liquid or solid ballasting material. Thus, the space between the two shells can be flooded with sea water or alternatively such space can be partially or completely filled with drilling mud, concrete, gravel, sand or some other suitable heavy solid material.

After the tank of FIG. **1** is placed on the sea floor, it can be used for the storage of oil. Valve **20** can be left open for sea water to flow in and out of space **17.** When oil is fed to space **17,** it floats on the water and forces sea water out through conduit **19.** When oil is removed from the tank, sea water flows in through conduit **19.** Thus, the entire space **17** is always full of liquid.

FIG. **2** illustrates another embodiment of enclosure which can be employed for an offshore liquid storage tank. Enclosure **25** has a plurality of spaced apart hollow tubular ribs or members **26** which radiate downwardly from a central top area of the enclosure. Tubular members **26** are hollow and are made sufficiently strong to withstand the pressure of the sea when the enclosure rests on the sea floor. The generally dome-shaped enclosure **25** also has a plurality of horizontally positioned spaced apart hollow tubular ribs or members **27** which intersect with, and communicate internally, with radially located tubular members **26.** FIGS. **3** and **4** show in somewhat greater detail the intersection of the tubular members **26** and **27.** The area between spaced apart adjacent tubular members **27** and between spaced apart adjacent tubular members **26,** is filled by plate members **28** welded to the tubular members **26** and **27.** Conduit **29** communicates with the upper interior space **30** encompassed or enveloped by enclosure **25** so that air may be vented from such space through valve **31** during submergence thereof. Conduit **32** communicates with the lower interior space or volume enveloped by enclosure **25** and provides a means for flow of sea water into and out of such space. Valve **33** is provided to control such sea water flow through conduit **32.**

Enclosure **25** floats with inherent stability on water because of the substantial cut-water plane created by the tubular members **26** and **27** when they are immersed in water. It should be understood that the size of the tubular members **26** and **27** must be adequate to provide a cut-water plane righting moment sufficiently large to bar uncontrolled tilting or capsizing of enclosure **25.** If desired, the lower part of tubular members **26** and one or more of the lower horizontal tubular members **27** can be filled with ballasting material to lower the center of gravity of the enclosure to further increase its inherent stability.

The enclosure of FIG. **2** can be submerged in the same manner as described with reference to the structure of FIG. **1.** Appropriate conduits and valve means can be provided to selectively add ballasting material, either solid particulate material or a liquid, to any or all of tubular members **26** and **27.** Appropriate partitions or bulkheads can also be inserted at any suitable location within tubular members **26** and **27** to retain such ballasting material in predetermined locations in order that the ballast will be maintained in position and not slide or flow to one side of the enclosure and create an imbalance with loss of stability during floating and submerging.

FIG. **5** illustrates another embodiment of enclosure which can be used for an offshore liquid storage tank. Enclosure **40** is generally dome-shaped and has a plu-

rality of metal tubular ribs or members **41** which radiate outwardly and downwardly from a central top portion of the enclosure. The central top portion of enclosure **40** has a flat metal plate **42,** circular in shape, which is joined to a toroidal or circular tubular member **43** from which tubular ribs **41** project outwardly and downwardly. Metal plates **44** join adjacent radial tubular members **41** in rigid fixed spaced apart position. Conduit **45** communicates with the interior upper space enveloped by enclosure **40** so that air can be removed from beneath the enclosure during submergence of the structure. Valve **46** in conduit **45** controls flow of air therethrough. Conduit **47** communicates with the lower interior space enveloped by enclosure **40** and flow of sea water therethrough is controlled by valve **48.** The lower ends of radial tubular members **41** are sealed off by plates **39** so that such members provide buoyancy for enclosure **40.**

The enclosure of FIG. **5** possesses inherent stability when floating on a sea surface because of the large cut-water plane, and the corresponding righting moment thereby developed, through the presence of the large radial tubular members **41.** The enclosure of FIG. **5** can be submerged in the same way as described with respect to the enclosure of FIG. **1.** Furthermore, to aid in submerging enclosure **40** or to ballast it to more firmly seat it on a sea floor, a conduit **49** and a conduit **50** are provided in communication with each of radial tubular members **41.** Conduit **49** can be used to supply a ballasting material, such as water or sand, to tubular member **41** and the other conduit **50** can be employed to vent air therefrom during the ballasting operation.

Another embodiment of enclosure is illustrated by FIG. **6.** The enclosure **50** of this embodiment is generally dome-shaped and approximates a semispherical shape. Enclosure **50** comprises a plurality of tubular toroidal ribs or members **51** positioned parallel to one another in spaced apart horizontal arrangement. Adjacent tubular toroidal members **51** are joined together by spherical shell segments **52** such as by means of welds. Each of the toroidal members **51** is advisably provided with two conduits **53** and **54** in order that the interior of each tubular toroidal member **51** can be ballasted. Thus, a solid or liquid ballasting material can be supplied by conduit **53** and air vented therefrom by means of conduit **54.** Tubular toroidal members **51** are made of sufficient size to provide an adequate righting moment when the enclosure floats on the sea surface with air entrapped below the enclosure. The bottom of enclosure **50** is open to the sea so that, when air is vented therefrom by means of conduit **55** with valve **56** open, the enclosure will slowly settle or submerge. When all air has been removed from the space enveloped by enclosure **50,** and that space is fully occupied by sea water, the enclosure will have sufficient buoyancy to be maintained at a floating level with only a small upper portion of the enclosure above sea level. Further submergence of the enclosure can be achieved with controlled stability as described with reference to FIG. **1.** Once the enclosure has been positioned on the sea floor, conduit **57** with valve **58** opened, can be employed to control flow of sea water to and from the space enveloped by the enclosure. To use the structure for the storage of oil, oil can be pumped in through valve **56** and conduit **55** and sea water displaced from beneath the enclosure through conduit **57** with valve **58** open. When oil is removed from beneath enclosure **50** by conduit **55,** sea water flows in through conduit **57** and occupies the space.

The offshore liquid storage tank of FIG. **7** is adapted to rest underwater on a sea floor. The tank **60** has an enclosure **61** comprised of an inner semispherical metal shell **62** having a radius of **139** feet and a concentrically positioned semispherical outer metal shell **63** with a radius of 148 feet. The space between the inner shell **62** and the outer shell **63** is about **9** feet and such space is filled with a buoyant material **70** and advisably with small hollow glass spheres which can stand a substantial compressive force. The bottom portion of enclosure **61** has a ballasting ring wall **64** of concrete which is about **6** feet wide and **15** feet tall. Mounted on top of enclosure **61** is tubular column **65** of about 40 feet in diameter. On top of such column is platform **66.** The height of the offshore structure of FIG. **7** from the top of the platform to the top of concrete ring wall **64** is about 290 feet.

With further reference to FIG. **7,** conduit **67** communicates with the space **68** enclosed or enveloped by enclosure **61.** Conduit **67** can be used to withdraw air from space **68** during submergence of the offshore storage structure and the flow of air therefrom can be controlled by valve **69** therein. After the tank has been positioned on the sea floor, conduit **67** can be used to feed oil into space **68** for storage therein. Conduit **74** communicates with the lower portion of space **68** enveloped by enclosure **61** and, with valve **75** open, permits sea water to flow in and out of space **68.** When oil is fed to the space **68** through conduit **67,** sea water is displaced from space **68** through conduit **74** and when oil is withdrawn from space **68** through conduit **67,** sea water enters through conduit **74.**

The offshore oil storage structure of FIG. **7** floats on water with minimum draft. The weight of the structure is borne on the air entrapped in space **68** and uncontrolled tilting and capsizing of the structure is avoided because of the substantial cut-water plane and righting moment exerted by the wall width or thickness of enclosure **61.** Submerging of the structure is achieved by venting air from space **68** by conduit **67** and opening valves **73** and **76** so that buoyancy is transferred from the trapped air in space **68** to the buoyant material **70** in space **61.** Suitable means such as a screen through which water or air will pass but not the buoyancy material **70** is positioned in conduits **72** and **77** where they join outer shell **63.** After all of the air has been removed from space **68,** valve **69** is closed. After the structure load is transferred to the buoyant material **70,** the structure will still float due to the buoyancy provided by the buoyant material in the space between inner and outer shells **62** and **63** although at such point nearly all of enclosure **61** will be below the surface of the sea.

Further submerging of the structure of FIG. **7** is achieved by opening valve **73** and removing the screen in conduit **72** so that sea water can flow through conduit **77** into the space between shells **62** and **63** and the buoyant material **70** can flow out through valve **73.** The release of buoyant material is controlled so that the descent of the structure to the sea floor is always under control. As column **65** is pulled into the water, it provides stability for the structure. When the structure is finally deposited on the sea floor, all the buoyant material **70** in enclosure **61** is released. The enclosure **61** can then be filled with ballast in the form of stone, sand

or concrete supplied through conduit **72** or such other conduits or openings in enclosure **61** as are made for this purpose.

FIGS. **8** and **9** illustrate a further embodiment of an offshore structure provided by this invention. The offshore structure of these figures employs an enclosure **80** which has an internal semispherical metal shell **81** with a radius of 139 feet and an outer semispherical shell **82** with a radius of 144 feet. Thus, the inner shell **81** and the outer shell **82** are spaced 5 feet apart. Enclosure **80** has a concrete ring wall **83** about 40 feet high extending around the lower portion of the enclosure between inner shell **81** and outer shell **82.** Ring-like airtight compartments **84, 85, 86** and **87** are defined by spaced apart metal plate partitions **88, 89, 90** and **91** positioned between, and extending to, inner shell **81** and outer shell **82.** Platform **92** having a 200 feet diameter is supported by a plurality of legs **93** on top of enclosure **80.** Conduit **94** is employed for removing air from space **955** encompassed within and below enclosure **80.** Air is vented therefrom by conduit **94** with valve **95** open in submerging the offshore oil storage structure.

The offshore oil storage structure of FIGS. **8** and **9** floats on the sea with about a 9 foot draft with the space **95** pressurized to about 4 psig. The compartments **84, 85, 86** and **87** are pressurized with air to about 10 psig initially. Once the structure has been floated to the installation area, the air in space **95** is vented through conduit **94** until the partition **88** is about 45 feet below sea level. At such point, compartment **84** will be subjected to a net external pressure of about 10 psig. The pressure in compartment **84** is then raised to about 20 psig following which more air is vented through conduit **94** until the partition **88** is about 67 feet below sea level. At this point, compartment **84** is again at a net external pressure of 10 psig. Submergence is continued in this manner so that the net pressure on any of compartments **84, 85, 86** and **87** never exceeds 10 psig. Once all the air has been vented from space **95,** the enclosure **80** will be just about completely submerged but still floating. The structure can then be lowered further to the sea floor by an anchorcable means as described with respect to the embodiment of FIG. **1.** Once the structure is on the sea floor, a series of piles **96** can be driven into the sea floor through pile-receiving sleeves **97** supported by brackets **98** mounted on the lower outer portion of outer shell **82.** The piles can be grouted in place to the pile-receiving sleeves for excellent bonding. It should be understood that the offshore oil storage structure of FIGS. **8** and **9** is provided with such conduits and valve arrangements as are required to utilize it for its intended purpose.

The tank of this invention will normally have enclosures ballasted at the bottom of the wall, although ballast is not needed in theory, because the ballast will help to anchor the enclosure in place on the sea floor and help to avoid a need for the use of anchoring piles especially when all or part of the buoyancy space in the enclosure will is filled with ballast, such as after it is on the sea floor. The use of ballast on the bottom of the enclosure also aids in placing the center of gravity closer to the center of buoyancy, even though it advisably is still above the center of buoyancy when the tank has maximum floatation, to aid in the submerging operation.

The foregoing detailed description has been given for clearness of understanding only, and no unnecessary limitations shoud be understood therefrom as modifications will be obvious to those skilled in the art.

What is claimed is:

1. An offshore storage tank to be placed on the floor of a body of wather comprising:

a generally dome-shaped rigid continuous enclosure, open at the bottom and surrounding a large volume, said enclosure comprising an outer rigid semispherical shell and a smaller concentric inner semispherical shell, said shells being held in fixed position relative to each other by means of rigid connecting members joined to each shell, and ballast means closing the bottom of the enclosure between the shell ends, thereby defining a hollow enclosed space between the shells;

said hollow enclosed space constituting buoyancy means for providing buoyancy balance or equilibrium to the tank when the tank is floating on water with or without any amount of air in the large volume surrounded by the enclosure; and

conduit means communicating with the volume beneath the enclosure for removing air therefrom, whereby the enclosure can be lowered in water.

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